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# Influence of genotype and sowing date on camelina growth and yield in the north central U.S.

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ABSTRACT

Camelina (*Camelina sativa* L.) has gained considerable attention in North America as a potential oilseed feedstock for advanced biofuels and bioproducts. Progress has been made towards characterizing camelina's production potential for the western U.S. and Canada. However, little has been done to evaluate its potential for the north central region of the U.S. The objectives of the following study were to evaluate plant stand establishment, growth, and yield of 10 camelina cultivars and target the optimum sowing time for spring seeding in the northern Corn Belt. The study was conducted over three growing seasons between 2008 and 2010 in west central Minnesota, on a Barnes loam soil. Eight cultivars were evaluated in 2008, 10 cultivars in 2009, and four cultivars in 2010. Sowing dates ranged from 16 April to 15 June over the three-year study. Plant population density, time to 50% flowering, seed yield, and oil content were affected by sowing date, tending to decline with delayed sowing. Seed yield was significantly affected by cultivar only in 2009, whereas oil content was consistently affected by cultivar all three years. Across cultivars, seed yields were as high as 2300 kg $ha^{-1}$ to as low as 743 kg $ha^{-1}$ and were generally greatest for sowings between mid-April to mid-May. Across sowing dates and cultivars, oil content ranged from about 36 to 43% (wt $wt^{-1}$) and declined with delayed sowing. Generally, seed yield and oil content differences tended to be small between most genotypes in the study. Results indicate that the best time to sow spring camelina in west central Minnesota is from about mid-April to mid-May. Further research is needed to optimize other agricultural inputs for camelina production in the northern Corn Belt.



## 1. Introduction

In recent years camelina (*Camelina sativa* L.) has gained considerable attention in the United States and Canada as a potential oilseed feedstock for advanced biofuels and bioproducts. Although camelina has a long history as a cultivated oilseed crop in northern Europe and Scandinavia (Zubr, 1997), it is a relatively new crop to North America. The seed oil content of camelina typically ranges from about 35 to 45% (wt $wt^{-1}$) and has been found suitable for making biodiesel (Fröhlich and Rice, 2005), and recently has been shown to serve as an excellent feedstock for renewable aviation fuel (Shonnard et al., 2010).

Due to the high production cost of biofuels relative to petroleum-based fuels, which largely is a consequence of high feedstock cost (Demirbas, 2006), a major attraction of camelina is its relatively low agricultural input requirements (Robinson, 1987; Putnam et al., 1993; Gesch and Cermak, 2011) thus, keeping its production cost low compared to other feedstock. In North America, camelina is being developed primarily as an industrial crop and therefore, should not directly compete in the market place with commodity food, feed, and fiber crops. Moreover, camelina is resilient to limited soil moisture and freezing temperatures (French et al., 2009; Gugel and Falk, 2006) making it a good candidate to be produced on lands where high valued food crops such as maize (*Zea mays* L.) and soybean [*Glycine max* (L.) Merr.] may not be economically viable. Additionally, autumn-sowing winter annual types of camelina can allow potential for double-cropping with certain food and feed crops (Gesch and Archer, 2013) making it possible to produce biofuel and food on the same land in a single season with camelina serving as a "cash" cover crop.

Considerable effort has been made to characterize camelina's agronomic potential for the western and Great Plains regions of the U.S. (McVay and Khan, 2011; Pavlista et al., 2011; Schillinger et al., 2012; Lenssen et al., 2012) and Canada (Gugel and Falk, 2006; Blackshaw et al., 2011; Urbaniak et al., 2008a), but little attention has been given to its performance in the northern Corn Belt region of the U.S. Robinson (1987) was one of the first to report results of several field experiments conducted in the U.S. during the

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1960s and early 70s to evaluate the effects of various management practices on camelina including sowing date. Robinson compared camelina seed yields to those of other *Brassicaceae* oilseeds including *Brassica napus* and *B. juncea* and found in most cases that yields were comparable with fewer inputs, and also showed that early spring (mid-April) was a good time to sow camelina in central Minnesota. However, sowing date was not extensively tested and only one genotype was used.

With regard to camelina sowing date studies, results have varied. For instance, Urbaniak et al. (2008a) found no affect of sowing date on either seed yield or oil content for camelina grown in eastern Canada and Pavlista et al. (2011) found that yields were greatest when sown in late-March to late-April in the Nebraska Panhandle, U.S., although oil content was unaffected. In a three-year study conducted across four field sites in the Pacific Northwest, U.S., using the cultivar Calena sown between mid-October to mid-April at all sites, Schillinger et al. (2012) reported that yield responded to sowing date but that the response pattern varied at each of the four sites. Gesch and Cermak (2011) reported that seed and oil yields for the winter annual camelina cultivars Joelle and BSX-WG1 were optimal when sown in early October. These studies highlight the importance of characterizing the optimum sowing time of camelina for a given region as well as genotype.

Only a few studies have addressed the effect of cultivar on camelina seed yield and oil content. Among 30 camelina accessions evaluated by Vollmann et al. (2007) across three environments in Austria, seed yield was found to range from 1574 to 2248 kg $ha^{-1}$ and oil content ranged from 40.5 to 46.7% depending on cultivar. In a study evaluating 19 camelina accessions across three field sites in western Canada, Gugel and Falk (2006) reported that yields ranged from 962 to 3320 kg $ha^{-1}$ and oil content ranged from 38 to 43%. Urbaniak et al. (2008b) evaluated nine cultivars across three environments in eastern Canada and found seed yields significantly varied in the range of 552–2568 kg $ha^{-1}$ with oil content ranging from 36.2 to 40.1%.

Establishing best management practices, including sowing date, and selecting the most productive genotype(s) for a given region or environment will aid in optimizing camelina productivity while reducing feedstock cost for biofuel production. To date, no extensive evaluation of camelina germplasm or optimum sowing date has been made for summer annual production of camelina in the northern Corn Belt region of the U.S. Therefore, the present study was designed to evaluate the growth and yield of 10 camelina cultivars and target the optimum sowing time in west central Minnesota, U.S.

## 2. Materials and methods

### 2.1. Cultural practices

The present study was conducted over three growing seasons during 2008, 2009, and 2010 at the USDA-ARS Swan Lake Research Farm located 24 km northeast of Morris, Minnesota (45°35′N, 95°54′W). The soil was a Barnes loam soil (fine-loamy, mixed, superactive, frigid calcic hapludoll). The pH of soil at the study site is generally 7.2–7.3 and total organic and inorganic carbon ranges from 34.4 to 27.9 g $kg^{-1}$ in the surface to 0.6 m soil depth (Johnson et al., 2010). The experimental design was a split-plot randomized complete block replicated four times. The main plots consisted of sowing date and subplots consisted of cultivar. The size of subplots in 2008 was 1.8 m by 4.6 m and in 2009 and 2010 it was 3.7 m by 7.6 m. The smaller size in 2008 was due to a limited amount of seed for sowing. Bulk seed collected for each cultivar grown in 2008 was used for sowing the trials in 2009 and 2010. All camelina cultivars were sown at a rate of 4.5 kg $ha^{-1}$ on 30 cm spaced rows using a Wintersteiger plot drill (Model PDS 12R) with double-disk openers and using a seeding depth of approximately 1.0 cm.

Ten camelina cultivars were evaluated in the study. In 2008, Blaine Creek, Calena, CO46, CO54-97, Gold of Pleasure, Ligena, Robinson, and Suneson were grown. In 2009, the same cultivars were grown with the addition of Celine and Galena, and in 2010 only Calena, CO46, Blaine Creek, and Suneson were evaluated. All seeds used for the study were initially obtained from the North Dakota State University Extension Service (Fargo, North Dakota, USA). The genotype labeled Gold of Pleasure is likely a landrace that originated from Europe and was used in early breeding work in the U.S. The germination rate of seed used in the study was ≥90%. Sowing dates were targeted for as early as possible in the spring (typically mid-April to early-May in west central Minnesota, depending on field conditions) and then for early- to mid-May and late-May to early-June. Sowing dates were 23 April and 14 May in 2008; 4 May, 15 May, 29 May, and 15 June in 2009; and 16 April, 3 May, and 26 May in 2010. Only two dates could be sown in 2008 due to a limited amount of seed. In all three years of the trial, the previous crop was hard red spring wheat (*Triticum aestivum* L.). Prior to sowing camelina, the soil was chisel plowed in the autumn and in spring 90, 34, 45, 34 kg $ha^{-1}$ of N, P, K, S was incorporated into the soil by shallow disking. Urbaniak et al. (2008b) reported camelina yields did not respond significantly to N fertilizer above 60–80 kg $ha^{-1}$. The fertilizer rates used in the present study were such to try and eliminate fertility as a limiting factor. At the same time the fertility was added, trifluralin at a rate of 1.1 kg ai $ha^{-1}$ was also incorporated into the soil for weed control. Additional weeding was done by hand when necessary, but was minimal throughout the study.

### 2.2. Plant sampling and measurements

Seedling emergence and plant population density at harvest were measured on the same 1 m of row that was randomly selected and marked after sowing within the area used for harvest. This same 1 m of row was used for measuring the date when 50% of plants showed an open flower. Plant lodging was measured visually at the time of harvest using a scale of 0– 5 with 0 being fully erect and 5 being parallel to the ground. Growing degree days (GDD) were calculated as: $GDD = \sum(T_{max} + T_{min}/2) - T_{base}$, where $T_{max}$ and $T_{min}$ are daily maximum and minimum air temperature, respectively, and $T_{base}$ is base temperature of which a value of 5 °C was used (Blackshaw et al., 2011). Weather data including air temperature and precipitation were collected at a permanent weather station located at the study site.

Camelina was mechanically harvested with a plot combine. In 2008, due to the narrow plot width, the entire plot was harvested for yield. In 2009 and 2010, 5 rows from the center of each 12-row plot were harvested for yield. For a given sowing date, all cultivars were harvested at the same time after reaching full maturity, judged by when >90% of silicles had dried and turned brown and most seed was reddish-brown in color. Harvest dates were 28 July and 5 August for the first and second sowing dates in 2008; 4, 11, and 18 August and 1 September for the first, second, third and fourth sowing dates in 2009; and 16 and 27 July and 9 August for the first, second, and third sowing dates in 2010. Seed yield samples were dried in mesh bags in a forced air oven at 43 °C for 48–72 h before being screen cleaned. Moisture content of seed was determined immediately after cleaning by drying a subsample at 65 °C for 48 h and seed yields were adjusted to moisture content of 10%.

Seed oil content was measured by pulsed NMR (Bruker Minispec pc120, Bruker, The Woodlands, TX) as previously described by Gesch et al. (2005). Calibration of the instrument was performed with pure camelina oil. A subsample of approximately 5 g of seed of each replicate was used for analysis. Moisture content was determined according to AOCS (American Oil Chemist's Society) Method 2-75. Each sample was done in duplicate, dried at 130 °C for 4 h, and cooled in a desiccator for 15 min before oil analysis.

### 2.3. Statistical analysis

Data were analyzed by ANOVA using the Mixed Procedure of SAS (SAS for Windows 9.1, SAS Inst., Cary, NC). Data were analyzed separately by year. For the mixed model, cultivar and sowing date were treated as fixed effects. Mean comparisons were made by least significant difference (LSD) at the $P \leq 0.05$ level and for comparing amongst cultivars in 2008 and 2009 the Bonferroni adjustment ($P \leq 0.05$) was used.

## 3. Results and discussion

### 3.1. Climate conditions

The 2009 growing season was generally cool, especially during June, July and August when average monthly temperatures were 0.9, 2.3, and 1.3 °C below the 30-year average, respectively (Table 1). Conversely, 2010 was relatively warm during this same period with temperatures of 0.9 and 2.3 °C above average in July and August, respectively. From April through September, precipitation was below the 30-year average for 2008 and 2009, whereas it was near normal in 2010. However, in 2010, during August and September above normal precipitation was received, while below normal amounts were received in April, May, and July.

### 3.2. Plant population density and lodging

Plant stand establishment is a critical factor that can affect crop productivity and this has been reported as an issue with camelina (McVay and Khan, 2011; Lenssen et al., 2012). In the present study, plant population densities after final seedling emergence and at harvest were similar and therefore, only the data at harvest are reported. In all three years of this study, sowing date did significantly influence stand establishment and hence plant population density (Table 2). Although there was no clear trend in plant population with sowing date, in 2009 and 2010 there was a tendency for population to decline with later sowing date (Fig. 1). Plant population density was closely associated with soil temperature and precipitation. Dry conditions and high soil temperatures associated with sowing were major factors contributing to lower populations. Shallow-sown seed such as that for camelina that was seeded at a 1.0 cm depth in the present study is prone to be exposed to highly fluctuating soil temperature and moisture. For instance, in 2008 precipitation was lacking in April (Table 1) and the lower stand for the 23 April seeding was likely in part due to dry soil for an extended period. Conversely, the significantly higher stand for the 14 May sowing in 2008 was likely due to a timely rain event (24 mm on 10 May) that occurred a few days prior to sowing. However, during 2008, damage caused to seedlings by ground

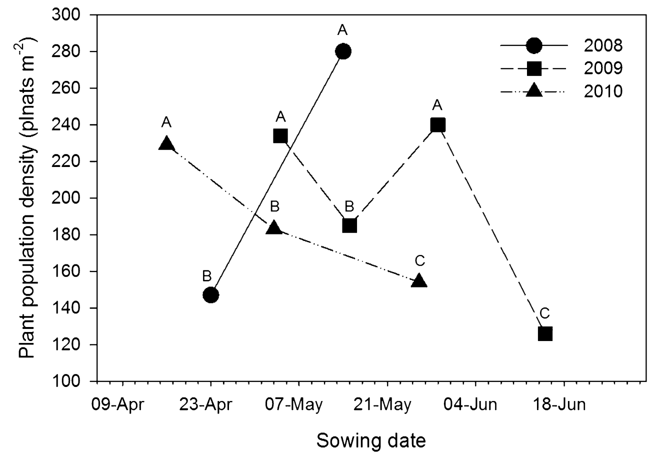


**Fig. 1.** Plant population density at harvest as affected by sowing date. Values are means across all cultivars for a given date. Values followed by the same letter are not significantly different at the $P \leq 0.05$ level.

squirrels (*Spermophilus tridecemlineatus*) also contributed to lower plant populations in some plots, which was mostly confined to the first (23 April) sowing date. The lowest population densities for the latest sowings in 2009 and 2010 were closely associated with high soil temperatures when during the first week after sowing, the daily maximum temperature at the 5 cm depth exceeded 30 °C. Conversely, the increase in population between the second and third sowing dates in 2009 was associated with two precipitation events, one that occurred just prior to the 29 May sowing and another 11 d later that together totaled 18 mm, during an otherwise dry month of May (Table 1). Similarly, Schillinger et al. (2012) also found that in the Pacific Northwest region that surface crusting caused by drying soil and lack of timely precipitation were primary causes of reduced camelina plant populations for various sowing dates when seeded shallow by either drilling or broadcasting seeding.

A significant cultivar effect for plant population occurred in 2008 and 2009 (Fig. 2). The cultivars Robinson and Blaine Creek consistently produced the highest plant density in both years when averaged across sowing dates, averaging 287 and 274 plants m$^{-2}$ in 2008, respectively, and 250 and 235 plants m$^{-2}$ in 2009. Ligena, Gold of Pleasure, and CO46 had some of the lowest average populations ranging from 127 to 187 plants m$^{-2}$ (Fig. 2). The range of plant populations averaged across sowing dates and cultivars in this study were generally similar to the range reported by Urbaniak et al. (2008a) for the cultivar Calena (112–282 plants m$^{-2}$) seeded at different rates (200–800 seeds m$^{-2}$). Schillinger et al. (2012) also used Calena in their experiments, which included four field sites and several sowing dates. In their study, averaged across sowing dates for the Lind, WA and Pendleton, OR sites, Calena drill seeded at 6 kg ha$^{-1}$ ranged from 30 to 135 plants m$^{-2}$ over three growing seasons. For comparison, in the present study when averaged across planting dates, Calena drill-seeded at about the same depth as Schillinger et al. (2012) but at a rate of 4.5 kg ha$^{-1}$ ranged from

**Table 1**
Monthly mean air temperatures and precipitation in 2008, 2009, and 2010 including the 30-year average at the study site.

| Month | Mean air temperature (°C) | | | | | Precipitation (mm) | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 2008 | 2009 | 2010 | 30-year Avg. | | 2008 | 2009 | 2010 | 30-year Avg. |
| April | 4.7 | 5.9 | 11.3 | 6.7 | | 7 | 18 | 29 | 58 |
| May | 12.5 | 13.8 | 14.7 | 13.9 | | 48 | 11 | 37 | 76 |
| June | 18.2 | 18.2 | 19.3 | 19.1 | | 97 | 41 | 88 | 98 |
| July | 21.8 | 19.2 | 22.4 | 21.5 | | 31 | 20 | 58 | 100 |
| August | 20.5 | 18.8 | 22.4 | 20.1 | | 58 | 70 | 166 | 84 |
| September | 15.6 | 17.3 | 14.4 | 15.0 | | 61 | 31 | 99 | 71 |
| Mean | 15.5 | 15.5 | 17.4 | 16.1 | Total | 303 | 191 | 476 | 487 |

**Table 2**
ANOVA for plant population density (PPD), seed yield, oil content, days from sowing to 50% flowering (d-50%-FLW), and accumulated growing degree days from sowing to 50% flowering (GDD-50%-FLW) as affected by cultivar (CV) and sowing date (SD) for camelina. Values are probabilities for the *F*-statistic.

| Year and effect | DF | PPD | Seed yield | Oil content | d-50%-FLW | GDD-50%-FLW |
|---|---|---|---|---|---|---|
| | | *P* > F | | | | |
| 2008 | | | | | | |
| CV | 7 | 0.0008 | 0.22 | <0.0001 | 0.0007 | 0.0004 |
| SD | 1 | <0.0001 | <0.0001 | <0.0001 | <0.0001 | <0.0001 |
| CV × SD | 7 | 0.55 | 0.14 | 0.57 | 0.74 | 0.75 |
| 2009 | | | | | | |
| CV | 9 | <0.0001 | 0.0005 | 0.03 | <0.0001 | <0.0001 |
| SD | 3 | <0.0001 | <0.0001 | <0.0001 | <0.0001 | <0.0001 |
| CV × SD | 27 | 0.63 | 0.20 | 0.38 | 0.0002 | 0.007 |
| 2010 | | | | | | |
| CV | 3 | 0.83 | 0.22 | <0.0001 | <0.0001 | <0.0001 |
| SD | 2 | <0.0001 | <0.0001 | <0.0001 | <0.0001 | <0.0001 |
| CV × SD | 6 | 0.68 | 0.18 | 0.89 | 0.02 | 0.06 |

182 to 219 plants $m^{-2}$. Although the germination rate of seed might have differed between studies, it is also likely that the difference resulted from soil type and precipitation patterns.

Cultivar-related differences in plant stand establishment in the present study may have been due to differences in seedling vigor following germination in the soil. However, seed size likely contributed the most to effecting plant populations. Robinson and Blaine Creek had the smallest seed sizes at 0.83 and 0.96 g $1000^{-1}$ seed, respectively, as compared to Ligena (1.5 g $1000^{-1}$ seed) and CO46 (1.4 g $1000^{-1}$ seed), which were the largest. Therefore, at the sowing rate used in the study, the seed population at sowing would have been greater for Robinson and Blaine Creek than the other cultivars.

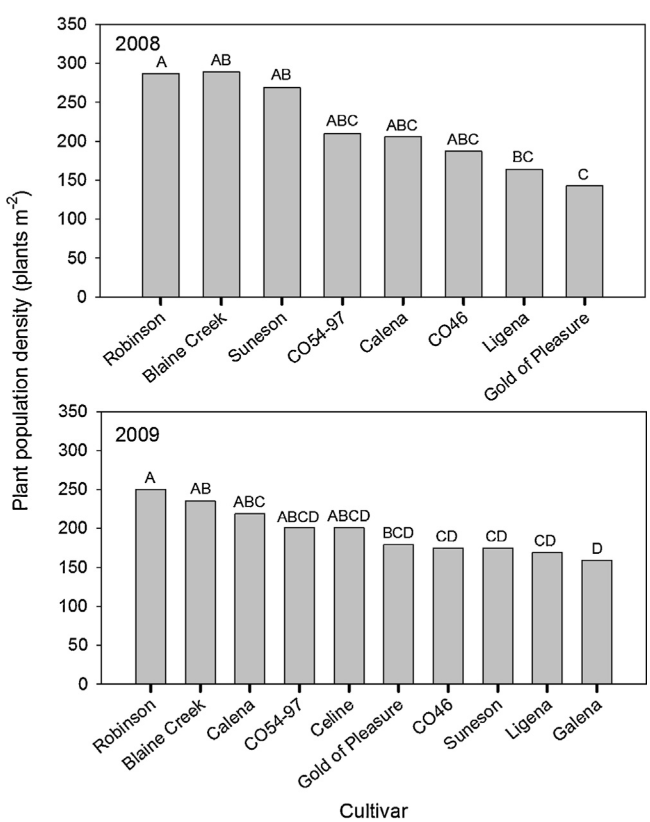


**Fig. 2.** Plant population density at harvest as affected by cultivar for the 2008 and 2009 growing seasons. Values are means across all sowing dates. Values followed by the same letter are not significantly different at the $P \leq 0.05$ level.

With regards to plant lodging, little information exists for *Camelina*. Gugel and Falk (2006) assessed lodging for 19 camelina accessions grown across three field sites in western Canada using the same scale as the present study, but observed little or no lodging, so no results were reported. Robinson (1987) also reported that camelina had good lodging resistance when compared to other Brassica oilseed crops. In the present study, camelina plant lodging was found to be essentially nil in 2008 and 2010, while in 2009 some damage was documented. The lodging in 2009 was associated with a few strong wind events due to thunderstorms that occurred during the primary growing season on 27 and 28 June, 9 July, and 14 July with wind speeds ranging from 13.7 to 17.8 m $s^{-1}$. These winds caused some extent of lodging to plants in all sowing dates. However, when averaged across sowing dates, the highest lodging score was only 1.9 for Celine and the lowest was 0.8 for Robinson (results not shown) on a scale of 0–5 with 0 being fully erect and 5 being horizontal to the ground. Overall, results from this study confirm that camelina is relatively resistant to lodging.

### 3.3. Flowering and harvest date

There was a strong influence of sowing date and cultivar on the number of days and accumulated GDD from sowing to 50% flowering (Table 2). Across years the number of days to 50% flowering decreased as sowing was delayed (Table 3), primarily due to increasing growth temperatures. Although accumulated GDD to 50% flowering significantly differed among sowing dates the differences were not large or very consistent. In both 2008 and 2010,

**Table 3**
Effect of sowing date on days from sowing to 50% flowering (d-50% FLW), accumulated growing degree days from sowing to 50% flowering (GDD-50% FLW), days from sowing to harvest (d-Harvest), and accumulated growing degree days from sowing to harvest (GDD-Harvest) for camelina. Within columns by year, values followed by the same letter are not significantly different at the $P \geq 0.05$ level.

| Year/sowing date | d-50% FLW | GDD-50% FLW | d-Harvest | GDD-Harvest |
|---|---|---|---|---|
| 2008 | d | °C d | d | °C d |
| 23 April | 59.2 a | 505 b | 100 | 1172 |
| 14 May | 42.8 b | 578 a | 83 | 1157 |
| 2009 | | | | |
| 4 May | 48.7 a | 510 b | 92 | 1139 |
| 15 May | 41.7 b | 501 c | 88 | 1159 |
| 29 May | 35.6 c | 469 d | 81 | 1125 |
| 15 June | 35.5 c | 544 a | 78 | 1134 |
| 2010 | | | | |
| 16 April | 53.5 a | 504 b | 91 | 1101 |
| 3 May | 47.5 b | 548 a | 85 | 1182 |
| 26 May | 36.6 c | 545 a | 75 | 1216 |

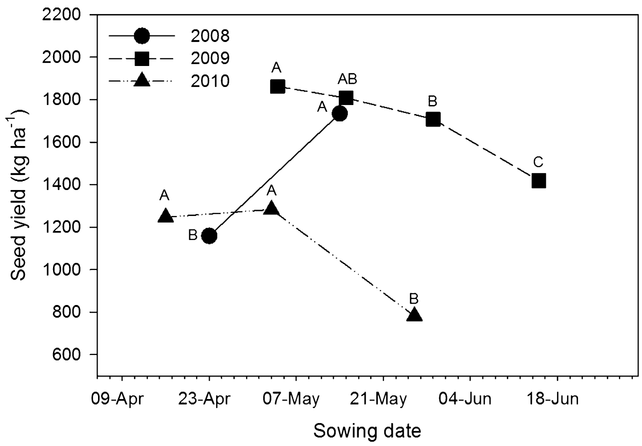


**Fig. 3.** Seed yield as affected by sowing date. Values are means across all cultivars for a given date and year. Values followed by the same letter within a year are not significantly different at the $P \leq 0.05$ level.

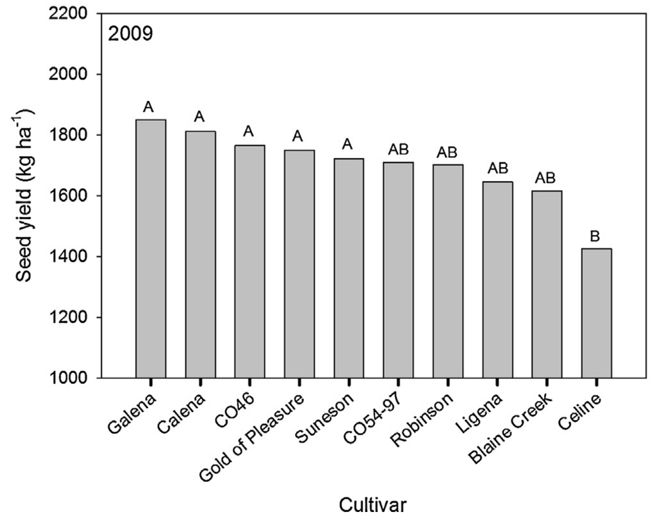


**Fig. 4.** Seed yield as affected by cultivar across all sowing dates in 2009. Values are means across all sowing dates. Values followed by the same letter are not significantly different at the $P \leq 0.05$ level.

there were fewer GDD accumulated for the earliest sowing date for each year.

The cultivar effect for days and GDD to 50% flowering was significant, but the actual difference between most cultivars was small. The range in d to 50% flowering across cultivars was 47–54 d in 2008, 38–42 d in 2009, and 44–47 d in 2010 (data not shown). However, the only consistent and noticeable difference was that CO46 was about 3–7 d earlier and required about 22–99 °C d fewer GDD units to flower and mature than the other cultivars. For a given sowing date, all cultivars were harvested at the same time after reaching full maturity and therefore, statistical analysis was not performed for days and accumulated GDD to harvest. As expected the number of days to harvest decreased with delayed sowing as growing season temperature increased (Table 3). However, the number of accumulated GDD from sowing to harvest differed little among sowing dates indicating that harvest maturity for spring camelina tends to be dependent on the accumulation of thermal time. This information will be useful for producers to predict harvest date for camelina depending on time of sowing. When averaged across all sowing dates for all three years, the number of days to harvest was 86. For comparison, when averaged across field sites and years, the number of days to maturity for camelina in the study by Gugel and Falk (2006) was 92 and for that of Blackshaw et al. (2011) was 91, both of which studies were conducted in the western prairie region of Canada.

### 3.4. Seed yield and oil content

Seed yields were significantly affected by sowing date in all three years (Table 2). In 2009 and 2010, the latest sowing date resulted in the lowest yields (Fig. 3). In 2009 there was a pattern of decreasing yield with sowing date, although the first and second sowing dates did not significantly differ. Pavlista et al. (2011) reported that camelina yield but not oil content was affected by sowing date, with early spring sowing resulting in highest yields in Nebraska, U.S. However, Urbaniak et al. (2011a) found no effect of sowing date on either seed yield or oil content in eastern Canada. In the present study, the relatively low yield for the 23 April sowing in 2008 averaged across all cultivars was likely due to poorer stand establishment than the second sowing date (Fig. 1) caused by a combination of poor emergence and rodent damage. Averaged across cultivars, yields were generally greatest in 2009 (Fig. 3), which was characterized by a cool dry growing season (Table 1). Data reported by others also indicates that relatively cool dry conditions may favor high camelina seed and seed oil yields (Gugel and Falk, 2006).

Seed yields were substantially lower in 2010 compared to 2009 and the 14 May sowing date of 2008. It is likely that high growing season temperatures are responsible for the lower yields in 2010. However, there was also an infestation of downy mildew (*Hyaloperonospora camelinae*) in camelina in 2010, which did not occur during the 2008 and 2009 growing seasons. Downy mildew can substantially reduce camelina seed production (Putnam et al., 2009). The combination of high temperatures and near normal precipitation in 2010 led to high humidity during mid-summer of the growing season, resulting in prime conditions for downy mildew infestation (McVay and Lamb, 2008). Other researchers have reported yield-losses in camelina due to downy mildew infestation (Urbaniak et al., 2008b; Schillinger et al., 2012) and have cited warm humid growing season conditions as likely contributing to increased disease incidence. In the present study, disease infestation during 2010 occurred in all cultivars, and to some extent in all three sowings, but was by far greatest in the latest (29 May) sowing. Averaged across all cultivars during the three-year study, yield was as high as 1862 kg ha$^{-1}$ for the earliest sowing in 2009 and as low as 782 kg ha$^{-1}$ for the latest sowing in 2010 (Fig. 3).

There were seed yield differences among cultivars in 2009 when averaged across sowing date (Table 2). Yield differences were relatively small amongst most cultivars in 2009 (Fig. 4). However, with respect to Calena, CO46, Suneson, and Blaine Creek, which were grown across all three years of the study, Calena tended to yield the highest and Blaine Creek the lowest. But again, it should be stressed that yield differences were generally small and seldom significantly different. The cultivar Celine was also found to be consistently low yielding across all four sowing dates in 2009. The highest yields for individual cultivars occurred in the earliest sowing date in 2009 (4 May), where yields were as high as 2303 and 2073 kg ha$^{-1}$ for Calena and CO46, respectively. In a trial that compared nine camelina cultivars across six different field site-years, Urbaniak et al. (2008b) found Calena to be consistently high yielding with yields ranging from 906 to 2568 kg ha$^{-1}$. Furthermore, similar to the present study, they found Calena and CO46 to have the highest seed oil content compared to other cultivars studied.

Seed oil content was strongly influenced by sowing date and cultivar in all three years of the study (Table 2). In 2009 and 2010 there was a trend of decreased oil content with increased sowing date (Fig. 5). Again, the cooler growing season coupled with low precipitation in 2009 appears to have favored seed and oil production of camelina. In contrast, seed and oil production were lowest in

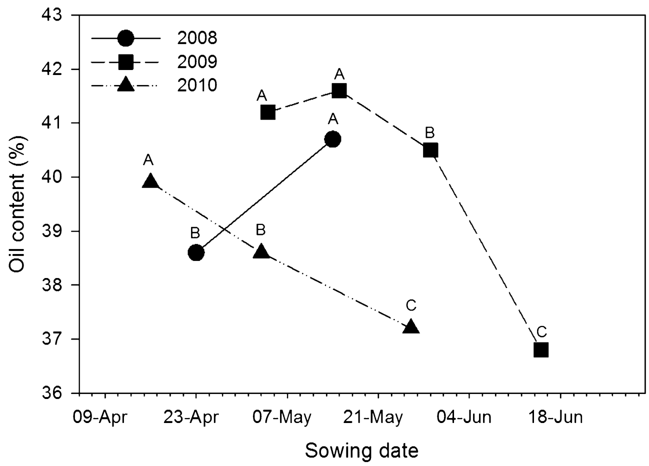


**Fig. 5.** Seed oil content as affected by sowing date. Values are means across all cultivars for a given date and year. Values followed by the same letter within a year are not significantly different at the $P \le 0.05$ level.

2010, which was hotter and wetter. As previously noted, the infestation of downy mildew during the 2010 season increased with later sowing, which also likely influenced the decline in oil content with sowing date. Oil content was a high as 41.6% when averaged across cultivars for the 15 May sowing in 2009. Across all sowing dates over the three-year study oil content ranged from 36.8 to 41.6% (Fig. 5).

Although cultivar differences in seed oil content were apparent in all three years of the study, much like seed yield, the degree of variation among most cultivars was relatively small (Fig. 6). Across all cultivars, when averaged over sowing dates, oil content ranged from 37.7 to 41.0% during the study. Again, for the four cultivars grown across all three years, Calena tended to have higher oil content than Blaine Creek and when compared to other cultivars in 2008 and 2009 was at the high end of the oil content spectrum (Fig. 6).

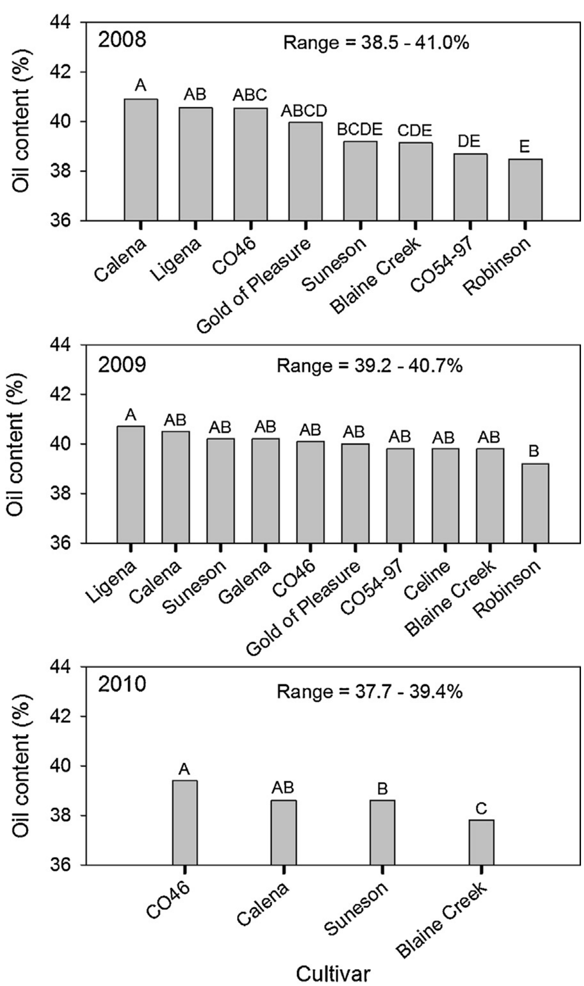


**Fig. 6.** Seed oil content as affected by cultivar. Values are means across all sowing dates. Values followed by the same letter are not significantly different at the $P \le 0.05$ level.

## 4. Conclusions

Spring camelina performs quite well as an oilseed crop in west central Minnesota, located in the north central U.S. Depending on genotype and sowing date, yields ranged from 743 to as high as 2303 kg ha$^{-1}$ with seed oil contents ranging from about 36 to 42%. Plant population densities varied considerably with respect to cultivar and sowing date across years, ranging from as low as 105 to as high as 407 plants ha$^{-1}$ and appeared to be influenced primarily by temperature and precipitation patterns. Results indicate that the best time to sow camelina for summer annual production in west central Minnesota is from about mid-April or as early as possible based on field conditions, to mid-May, which offers growers in the study region a relatively wide window of opportunity for sowing. Generally, the differences in seed yield and oil content among cultivar was relatively small, although the cultivar Calena did tend to be high yielding and contain higher seed oil content than some of the other genotypes in the study. Camelina has a short growing season, and therefore, should fit well as a rotational crop for the north central U.S. and serve as a viable oilseed feedstock for advanced biofuels and other industrial applications.

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